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AGARD ADVISORY REPORT No.283

Technical Evaluation Report of the Guidance and Control Panel 50th Symposium on

Computer Aided System Design and Simulation

(Système de Conception Aidé par Ordinateur et Simulation)

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

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Technical Evaluation Report

of the

Guidance and Control Panel 50th Symposium

on

Computer Aided System Design and Simulation

(Système de Conception Aidé par Ordinateur et Simulation)

by

Dr George T.Schmidt
The Charles Stark Draper Laboratory Inc.
(MS 2A)
555 Technology Square
Cambridge, Massachusetts 02139
United States

The Guidance and Control Panel 50th Symposium was held at the Altın Yunus Hotel, Çeşme/Izmir, Turkey, from 22nd to 25th May 1990. All the Papers presented at the Symposium were compiled as Conference Proceedings CP-473.

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– Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

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Published November 1990

ISBN 92-835-0595-6

Printed by Specialised Printing Services Limited
40 Chigwell Lane, Loughton, Essex IG10 3TZ

Theme

As guidance and control systems have become more complex, the role of computers in their design and development has become increasingly important. The results of simulation have been presented regularly in guidance and control symposia and, to a lesser extent, the use of computer design aids. However, it is considered that a symposium dedicated to computer aided design and simulation will provide a valuable opportunity to highlight the possibilities, the problems and solutions in this important field.

Computer aided design and simulation find applications at all stages of a project's life, starting with the conceptual design phase in which a basic system is defined and its performance evaluated using standard or special purpose design aid tools and simulation software. In the subsequent development of the system the effects of individual components or subsystems such as filters, limiters and other non-linearities, sensor and actuator dynamics, and embedded computer algorithms, are progressively quantified. In the later stages of development and evaluation, the complete system is simulated in sufficient detail to verify system performance against specifications.

As system development proceeds, increased emphasis is placed on real time computer simulation, with some or all of the hardware included in the simulation, depending on the phase of the project. Hardware-in-the-loop simulation includes the special case in which a human operator is included.

The aim of the symposium was to cover all stages of the development process. (KR)

Thème

Au fur et à mesure que les systèmes de contrôle et guidage deviennent de plus en plus complexes, le rôle des calculateurs dans leurs phases de conception et de guidage est devenu de plus en plus important. Les résultats de simulation ont été régulièrement présentés dans les symposia de guidage et pilotage, et à un degré moindre, l'utilisation d'aide à la conception des calculateurs. On espère cependant qu'un symposium dédié à la conception assistée par ordinateur et à sa simulation offrira une opportunité appréciable de mettre en lumière les possibilités, les problèmes et les solutions dans cet important domaine.

La conception aidée de calculateurs et sa simulation trouve des applications à tous les stades du projet, en commençant par la phase de conception dans laquelle un système de base est défini et ses performances évaluées en utilisant un outil d'aide standard ou spécifique, ainsi que la simulation du logiciel. Lors des développements ultérieurs du système, les interactions de chaque composant ou sous-système, tels que filtres limiteurs et autres non-linéarités, dynamique des capteurs et actuateurs, et logiciels câblés sont progressivement quantifiées.

Dans les développements et phases d'évaluation ultérieurs, le système complet est simulé avec suffisamment de précision pour confronter les performances du système avec les spécifications.

Lors du développement du système, une attention plus grande est portée à la simulation en temps réel, en incluant partie ou totalité du matériel, suivant l'avancement du projet. La simulation qui inclut du matériel dans la boucle comprend le cas particulier où l'homme est dans la boucle.

Le symposium avait pour but de couvrir tous les stades du développement.

Preface

This symposium was intended to cover the applications of computer aided design and simulation in the development of guidance and control systems. Topics covered in each of the six sessions included:

I. Computer Aided System Design

II. Simulation Technology for Missile Applications

III. Simulation Technology for Aircraft Applications

IV. Hardware-In-The-Loop Simulations

V. Systems Applications

VI. Pilot-In-The-Loop Simulations

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Department of Aerospace Engineering
Delft University of Technology
Kluyverweg 1
2629 HS Delft
The Netherlands

Deputy Chairman: Professor E.B.Stear
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376 Loew Hall – FH10
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PANEL EXECUTIVE

From Europe:
Commandant M.Mouhamad, FAF
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AGARD-OTAN
7 rue Ancelle
F-92200 Neuilly-sur-Seine
France
Telephone: 33 (1) 4738 5780
Telex: 610 176F
Fax: 33 (1) 4738 5799

From USA and Canada only:
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Attention: GCP Executive
APO New York 09777

HOST PANEL COORDINATOR

Professor Dr Ozay Oral
Dean, Faculty of Engineering and Science
Vice President, Bilkent University
PK 8 Maltepe, Ankara
Turkey

ACKNOWLEDGEMENTS/REMERCIEMENTS

The Panel wishes to express its thanks to the Turkish National Delegates to AGARD for the invitation to hold this meeting in their country and for the facilities and personnel which make the meeting possible.

Le Panel tient à remercier les Délégués Nationaux de la Turquie près l'AGARD de leur invitation à tenir cette réunion dans leur pays et de la mise à disposition de personnel et des installations nécessaires.

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on the
GUIDANCE AND CONTROL PANEL
50th SYMPOSIUM
on
COMPUTER AIDED SYSTEM DESIGN AND SIMULATION

by

George T. Schmidt
Charles Stark Draper Laboratory, Inc.
555 Technology Square
Cambridge, MA, U.S.A.

EXECUTIVE SUMMARY

The 50th symposium of the AGARD Guidance and Control Panel (GCP) was convened in Cesme, Turkey, 22-25 May 1990. The symposium dealt with the use of computers in system design and simulation. The program, as presented at the symposium, is appended to this report. The overall theme is described in the following paragraphs.

As guidance and control systems have become more complex, the role of computers in their design and development has become increasingly important. The results of simulation have been presented regularly in guidance and control panel symposia and, to a lesser extent, the use of computer design aids. However, it was considered that a symposium dedicated to computer aided design and simulation would provide a valuable opportunity to highlight the possibilities, the problems and solutions in this important field.

Computer aided design and simulation find applications at all stages of a project's life, starting with the conceptual design phase in which a basic system is defined and its performance evaluated using standard or special purpose design aid tools and simulation software. In the subsequent development of the system the effects of individual components or subsystems such as filters, limiters and other nonlinearities, sensor and actuator dynamics, and embedded computer algorithms, are progressively quantified. In the later stages of development and evaluation, the complete system is simulated in sufficient detail to verify system performance against specifications.

As system development proceeds, increased emphasis is placed on real-time computer simulation, with some or all of the hardware included in the simulation, depending on the phase of the project. Hardware-in-the-loop simulation includes the special case in which a human operator is included.

The symposium was intended to cover all stages of the development process. Thirty-one papers were presented and they did, in fact, cover all stages of the development process - from computer-aided preliminary design through hardware-in-the-loop simulations. The summary comments presented will focus on trends and results presented and some observations.

A major development observed was on the increasing use of workstations and microcomputers to do the jobs that were formerly performed by large mainframe computers. The smaller machines have always been superior to mainframes in terms of user turn-around time, user-friendliness and graphical capability. Now with the use of reduced instruction set computers (RISC), the smaller machines have central processing unit times which are competitive with those of super-computers. The cost of the small machines is measured in thousands rather than millions of dollars and the small army of technicians, required for the mainframes, have been eliminated. This leads to much more "bang/buck", as was defined by one of the authors at the symposium.

Another trend observed was the increasing use of computer graphics and computer visualization. The interactive nature of the microcomputer and workstation permits a real-time visualization of events which is not possible with a mainframe. Again this is being made possible by special processors and/or workstation/microcomputer capabilities. Image formation, which has been used by Hollywood for nearly a decade, seems to have come of age in this new engineering computer

environment. The use of computer graphics and visualization should aid in the understanding of and speed up the guidance and control design process.

One paper reported on the use of TRANSPUTERS in parallel processing architectures. TRANSPUTERS are devices that aim to avoid the problems of conventional serial processors by providing four links that can be connected to four other TRANSPUTERS. TRANSPUTERS, which originally needed a special programming language and a new way of programming, are being used in many applications with alternate software languages, such as ADA, and toolsets now becoming available.

Several papers reported on the uses of high-level symbolic programming languages as opposed to the traditional lower-level FORTRAN approach. In one approach, differential equations are coded as they would appear mathematically and integrations are automatically handled by the higher-level language. It is clear that the trend is to making "user-friendly" simulation and analysis packages available to the engineer at every level of aerospace design.

A minor disappointment, if it could be called that, was a lack of sufficient papers to explain the methodology to be applied in developing various simulations. Methodology applies to theory and application (the how and the why). Too many of the papers presented the results rather than the reasoning that led to the approach taken. It is not useful to hear about specific proprietary software or simulation packages (generic to a company or facility) that cannot be used anywhere else; at least, lessons learned should be presented, as well as, alternate approaches.

The major disappointment was the lack of papers dealing with the methodology and new techniques relating to overall approaches for computer-aided system <u>design</u>, possibly in a paperless environment. For several decades now, the engineering design and evaluation process has benefitted from the availability of general purpose analog and digital computers. What is now emerging is intelligent, paperless design environments. These design environments can be viewed as a logical extension of recent developments in CAD/CAM/CAE tools and software development environment. Rapid progress in parallel and distributed computation, man-machine interfaces, and computer science now affords an opportunity to create integrated design environments that will make it possible to: (1) explore more of the design solution space, earlier in the design process, (2) make the performance/reliability impacts of design tradeoffs more visible during the design process, (3) enforce design discipline and adherence to standards throughout the design process, (4) prevent/detect design errors, (5) resolve design conflicts, (6) facilitate more timely communication and coordination among designers and managers, and (7) capture and document the design process. While some of these topics were covered in a fragmented way, no unified picture of computer-aided system design in a paperless environment emerged. Further comments on this topic are in the Conclusions Section.

Not withstanding those disappointments, the symposium achieved most of its objectives in bringing together in a timely fashion, many of the leading engineers in this particular field. Both the Program Committee and National Hosts should be congratulated for their outstanding efforts in arranging the symposium.

INTRODUCTION

The 50th symposium of the GCP was titled "Computer Aided System Design and Simulation". The Program Chairman was Mr. Stanley Leek (UK). The Program Committee also included:

Dr. André Benoit	BE
Dr. Marc J. Pelegrin	FR
Pr. Dr. Ing. Reiner C. Onken	GE
Ir. Pieter Ph. van den Broek	NE
Pr. Dr. Ozay Oral	TU
Mr. Sterling Haaland	US
Pr. Edwin B. Stear	US

The welcoming address was presented by Col. D. Kaya, Chief, Dept. of Research and Development, Ministry of National Defense, TU. He pointed out the advantages of using computers to develop precise guidance and navigation systems to obtain a qualitative advantage in new weapon systems and also expressed his appreciation for the opportunities that the meeting would provide for the attending TU scientists and engineers.

The keynote address was presented by Mr. David Humphries, Assistant Chief Scientific Advisor (Projects and Research), MOD, Whitehall, U.K. Based on his experiences, he stated that there were numerous uses for computers in the simulation and exploration of future system concepts. They allowed alternative system concepts to be explored and emulated with a human operator in the loop, well in advance of system and concept requirement freeze. Computers allow tight configuration control during development and precise specification of the final chosen system, as well as, a topdown design approach. Mr. Humphries described the very important benefit that comes from this new found ability to "try it before you buy it"; i.e., the use of extensive simulation to evaluate a novel concept in a realistic environment. He mentioned that the advantages offered through computers include a possibility of a "virtual cockpit" where all the information available to the pilot is presented to him by electro-optical means.

Another idea he presented was that of a "universal simulator" whose underpinning was powerful digital computation, universal displays under software control, and the ability to replace elements of the simulation with the real hardware for "in-loop" evaluation. It would be used for concept development, interface development, requirements capture, subsystem acceptance, weapon system training, and in-service maintenance.

His final remarks concerned the "bottom line". Extensive computer simulations should help to "get it right the first time" thus saving manpower, time, and skill resources.

TECHNICAL SESSIONS

SESSION I: COMPUTER AIDED SYSTEM DESIGN

The first session consisted of four papers that covered various aspects of computer aided system design. The first paper (Germanetti and Gimonet) discussed the contribution of various simulation tools to research on flight control laws as part of a helicopter optimization program. This paper, as well as others in the symposium, shows the need to validate models (e.g., via wind tunnel tests) used in accurate digital simulations.

The next paper (Ünyelioğlu and Özgüler) dealt with decentralized control for highly augmented fighter aircraft with emphasis on studying the effect of sensor failures. While most of the reported work was analytical, the computer was used to generate typical responses.

The third paper (Cavallo et al) presents a design method for robust stabilizing controllers for single-input, multi-output systems based on redundant compensators and on a computationally tractable robust stability test in parameter space. As in the previous paper, the results were very analytical with the use of the computer limited to generating typical responses for the example under consideration (F4-E).

The last paper (Langer) is this first session addressed how complex aircraft control systems might be efficiently designed and simulated with the aid of artificial intelligence tools. It was shown how a symbolic manipulation program (MACSYMA) can be used to automate the steps which are necessary to design and simulate a control system with the landing phase of the MRCA TORNADO taken as an illustrative example.

Of the four papers presented in this session, the first three presented topics with the computer used in the traditional role during design. The last paper introduced the notion that an expert program can be used as a central development tool for the design, analysis, and documentation of a flight control system. One can certainly expect the expanding use of symbolic manipulation programs in design of future systems as engineers become aware of their power and flexibility. The Conclusions and Recommendations Section of this report will add several comments on design in a paperless environment.

SESSION II: SIMULATION TECHNOLOGY FOR MISSILE APPLICATIONS

The five papers in this session dealt with various aspects of simulation technology and applications for various vehicles. The first paper (Bertrand and Breuzet) uses digital computer simulations in the traditional manner to reduce a strapdown imaging IR seeker's size and cost by evaluating various designs using complete models of the missile, sensor, and the phenomenology of image processing. Tradeoffs were presented to show the utility of the simulation that was developed.

The second paper (Berton et al) described a simulator of approximately 200,000 lines of source code, including comments, that is used in the development of navigation systems at SAGEM. The simulation is used during the conceptual design phase, then in developing technical specifications, evaluations of algorithms, validation of on-board real-time software, and the evaluation of the navigation system on different mission profiles. An example of the use of the simulation in defining a new alignment algorithm was given.

The third paper (Quesada et al) comprehensively described the use of simulations as a project tool during all stages of the design of a laser guided weapon. The digital simulation used consists of about thirteen modules that cover all system elements (from aerodynamics to sensor processing). It was also used in developing the on-board software. A hardware in the loop simulator was described, as well as, actual hardware and software testing that compared favorably with a Monte Carlo study using both simulations.

The fourth paper of the session (Silson and White) described and demonstrated a weapon system design and simulation package used both as a research and development design tool, as well as, a computer-aided learning demonstration package. It is currently installed in stand-alone and networked IBM PCs and Sun workstations. This well-presented paper illustrated the possibilities of teaching missile guidance with a user friendly simulation package. The presentation gave an example using the control system design for a guided missile where the student used the simulator to study the missile response under closed loop control. Effects of lags, gains, guidance loop stiffness, etc., are all easily varied and their effects observable. This paper clearly illustrated a versatile computer aided design tool.

The last paper in the session (Zarchan) showed the power of the microcomputer in solving guidance and control problems including the visualization of results. Several interceptor guidance system related examples, which were until recently solved on large mainframe computers, were presented. An interesting comparison table of a rate gyro flight control simulation showed that the current generation of desktop computers appear to run at speeds within an order of magnitude of the large mainframes but with orders of magnitude lower acquisition and maintenance costs. When actual turnaround times for computer runs are considered, microcomputers appear even more favorable against the mainframe.

In summary, the five papers in this session covered a variety of simulation applications. The first three dealt with traditional uses of simulations and the last two papers with microcomputer based approaches. It is clear that for many problems the microcomputer simulation approach has become a very attractive alternative to the large mainframe based simulation.

SESSION III: SIMULATION TECHNOLOGY FOR AIRCRAFT APPLICATIONS

There were seven papers presented in this session. The first (Mattissek) described a project where the application software used in the system simulation was written in ADA to facilitate direct portability to operational software. Most avionic software requires extensive simulation of avionic specific algorithms during the systems analysis phase. Traditionally, these programs are written in FORTRAN. Then, for the development of operational software the same algorithms are re-coded in assembly language or a higher order programming language such as ADA. Mattisek goes on to describe two projects involving attitude and heading reference systems where this approach was tried. A FORTRAN to ADA translator was constructed to take advantage of existing FORTRAN modules. While his approach did not go far enough to quantify schedule reductions and cost savings, the initial successes should lead to further applications to building a library of common ADA packages which cover a spectrum of application software.

The second paper of the session (Döring) describes a simulation study performed to establish the task knowledge required by a pilot to make a correct automated landing approach and to identify information flow requirements for the pilot - cockpit interface. The goal of the study was development of a simulation supported technique which can be used in early system development for determining required knowledge of the pilot in rule-based situations and human engineering design and arrangement requirements for the cockpit-interface. A high level simulation language (SLAM) was used to implement a model and exercise it dynamically on a digital computer.

The next paper (Maes and Willems) presented the main features of a multi-purpose computer program which provides the equations of motion of aircraft in symbolic form and can be used in various testing and simulation procedures.

The fourth paper of the session (Schirle) presented a description of the formal approach and simulation tools used in the development of avionics systems for the MIRAGE 2000-5 and the RAFALE D at Avions Marcel Dassault and other companies in France during this past decade.

The next paper (Mangiacasale et al) provided a description of how computer aided design, synthesis and analysis tools are used at Aermacchi, IT. For each of these three application areas, the presenter described the tools employed. In general, the Linear Quadratic Regulator approach is the initial design approach followed by various sub-optimal implementations.

The sixth paper (Weber) described a tandem helicopter cockpit simulation facility used as a tool for providing specifications for development programs. A simulation system naturally drives the displays in response to pilot or command inputs in an attempt to study work imposed on the crew and possible automation of tasks.

The seventh and final paper (Tomlinson et al) of this session described the environment for active control research in the Flight Management Department, RAE Bedford. Active control technology has brought a dramatic change to the way aircraft can be designed and flown. The aircraft control elements - sensors, actuators, and computers - can now be integrated to confer flight behavior of almost infinite variety within the dynamic envelope of the host aircraft. RAE Bedford has been conducting flight research for many years; this paper describes the general approaches used and the special facilities that have been developed.

In summary, this session covered a wide variety of applications of simulation technology within several of the NATO countries. Most of the papers provided in-depth descriptions of the approaches and facilities used at each particular organization.

SESSION IV: HARDWARE IN THE LOOP SIMULATION

This session had five papers, three of which were from the Naval Weapons Center, China Lake, CA. The emphasis of the session was on hardware in the loop simulations that are typically conducted in the latter stages of a research/development project just prior to the beginning of flight tests. These facilities are also usually used during or after flight tests to aid in failure analysis or possible product improvement. The first paper (Saager) described a facility at DLR, Braunschweig, GE that is used for real-time simulation. Two examples were described in detail: a ground based transport aircraft real-time simulation, and a ground based helicopter real-time simulation. A comprehensive

description of the facility was provided - from numerical integration techniques implemented to software V&V and to the comparison between simulated and real flight data.

The second paper (Licklider et al) described a facility used for tactical missile system integration and analysis at China Lake. The facility allows many missile components such as the seeker and the autopilot to be exercised, integrated and tested with target signals generated and transmitted across free-space. The facility was used in the AIM-9M development program and is attributable, in large part, to a 50% reduction in actual test firings required over previous versions (AIM-9L) of the missile. Thirty-four less test flights were required with a savings of about 50 million dollars while the development facility cost about 1/2 of that amount. The use of the facility led to the detection of several design and implementation flows that would have led to flight failures had firings occurred.

The next paper (Smith et al) described the development and testing of sea surface multipath models which are used to create the simulated environment necessary to evaluate tracking algorithms in the guidance computer of a semiactive missile. The modelling effort relied heavily on flight test data for insight and verification; consequently, the simulated test data showed a good correspondence with flights at low target altitudes. A 5 degree of freedom simulation is used. It contains extensive radio frequency environment and signal processing models and forms a closed-loop around the missile's embedded computer. A number of conclusions about what effects must be modelled are presented in the paper.

The next paper (Oertel et al) demonstrated a recent technology for real-time simulation systems and described the perceived advantages of using OCCAM software and TRANSPUTER hardware. TRANSPUTER is a processor that was developed by INMOS and funded by the European ESPRIT project. The language OCCAM was designed by the same company. The TRANSPUTER has been optimized to run OCCAM programs and differs from the classical von Neumann type machine in its specialized hardware scheduling and multiple communication links to perform parallel processing. The computer system was designed to achieve real-time simulation capabilities for the FALKE Shuttle. This flight vehicle is a seven meter long model of a reentry body which is used for a new aerodynamic flight test technique. The vehicle is lifted by a balloon to an altitude of about 45 kilometers. The model is dropped and accelerates in free-fall up to a flight Mach number greater than 1. This low-cost flight test approach will be used to validate supersonic and transonic predictions of aerodynamics and other parameters. The first mission was planned for mid 1990. More recently, TRANSPUTERS have been implemented with other software languages, such as ADA, and various toolsets.

The next paper (Holden) described the use of computer graphics workstations used at China Lake for simulation visualization and target generation. These tools have become invaluable for image processing, image analysis, visualization, and generation of realistic target and background scenes for laboratory testing of imaging seeker hardware. They are also being used in a host of other fields from molecular biology to computational fluid dynamics. This has all been made possible by two things: (1) the phenomenal increase in computational power and (2) the performance of low-cost graphics workstations based on RISC. Computer visualization focuses the vast power of the human visual system onto the problem.

In summary, this session covered some very interesting and well-presented applications of hardware in the loop simulations. In particular, the new technology of TRANSFUTERS was described in detail, benefits of hardware-in-the-loop simulators described in several of the papers, and the use of powerful workstations for computer graphics and visualization was detailed.

SESSION V: SYSTEMS APPLICATIONS

This session had five papers covering various systems applications. The first paper (Hurst and Flynn) described a "few on-few" simulation technique used in assessing methods of air defense. The main program is a critical event driven, Monte-Carlo simulation, which permits the user to represent a wide variety of land-based air defense system concepts. The simulation was categorized as one that fits in a region between detailed engineering simulations of engineering weapon sub-systems, such as missile guidance, and one that does full campaign analyses. Such a category of simulation is usually extremely useful in cost-effectively examining the relative importance and sensitivities of overall system performance to a wide range of sub-system characteristics. The paper

also fairly describes some of the disadvantages of the approach. Near-term planned modifications to the simulation include a new, graphics based, input/output interface.

The next paper (Benoit and Swierstra) described the work carried out by the Engineering Directorate of the EUROCONTROL Agency with a view to integrating airline requirements, crew reactions, and aircraft capabilities in simulations aimed at assessing future air traffic handling procedures. Such procedures involve the 4-D guidance of aircraft, any of which may possess individual 2-D, 3-D or 4-D navigation capabilities. Basically, two simulation approaches have been used. The first used the full-scale flight simulators operated by airline pilots to assess future 4-D ground/air traffic control procedures under realistic conditions. The second assessed the overall air traffic control loop using various models and pilot substitutes because of the many potential aircraft that could be involved. The ACCESS flight simulation facility has been successfully used in various large scale simulations. At present it can support, in real-time, the simulation of 50 aircraft simultaneously and 8 pseudo-pilot positions. Overall, a system was described that can be extremely useful in developing solutions to the present shortcomings in meeting operators' demands in terms of capacity and efficiency.

The next paper (Zywiel et al) describes a fairly typical, modern navigation systems simulation and analysis software package that has been used in integrated navigation system design. The software package consists of a trajectory generator, sensor simulation programs, a full scale simulator/processor, covariance analysis, optimal smoother, and INS reset removal program. It has been recently used on several system developments in Canada.

The fourth paper (Vepa and Kreuzer) provided many interesting details on the application of modelling and signal processing techniques in air defense. Simple and effective models that match the real world are necessary to process sensor signals in real-time and to estimate/predict flight path trajectories of the targets. Critical problems encountered in land-based, land-vehicle mounted and ship-based air defense systems are pointed out. Modelling of specific target types and target maneuvers is discussed. Methods of employing modelling and stochastic optimal estimation techniques to estimate and predict target flight trajectory in real-time are also explained. Both active and passive sensors are dealt with and factors to be considered in multi-sensor suite selection and integration are pointed out in this well-written paper.

The final paper (Dey and Kröger) described the uses of simulation during the system definition phase to design an aircraft and its systems having competitive performance in 1995. The system definition phase of an aircraft is obviously critical for various reasons; at least 85% of the life cycle cost is determined in this phase. The paper described four types of simulations to be developed: first, the simulation of single systems for the purpose of system engineering; second, a model for system monitoring and failure propagation; third, a test bench for stimulating and analyzing processor-based black boxes; and fourth, an experimental flight simulation.

All in all, the papers presented in this session varied greatly in emphasis and application to systems, thus demonstrating the wide variety of computer applications in modern aerospace systems.

SESSION VI: PILOT-IN-THE-LOOP SIMULATIONS

This final session consisted of five papers dealing with pilot-in-the-loop simulation; two of the papers were presented by pilots. The first paper (Kraft et al) described the Combat Mission Training Evaluation and Simulation System (COMTESS) which is an"autonomous" system for aircrew training. It uses the global positioning system (GPS) for accurate position determination and registration, is powered from the aircraft, and fits within a standard missile pod, e.g. a Sidewinder size cannister. This on-board capability thus alleviates the requirement for flight crew training at a dedicated installation such as the Air Combat Maneuvering Installation. Sensor images and other data are also recorded in flight; extensive and detailed real-time mission playback in a ground station provides the tool for accurate and comprehensive assessments of aircrew and aircraft performance.

The next paper (Dewey) described an Integrated Technology Development Laboratory (ITDL) at Boeing. He described how a "single" laboratory was developed to study highly integrated avionics systems. The design contains multiple laboratories capable of independent operation or

interconnected to time-shared computers and flight simulation resources. The facility was placed in a total TEMPEST environment with physical security to allow multiple secure and nonsecure programs to coexist. The approach allowed high-value assets such as flight simulation domes, motion tables, and computing resources to be reconfigured to support multiple programs on a daily basis. There are three domes and cockpits. Each dome has a 9 meter, 360 degree-field-of-view and two computer image generation systems to provide simulated high-threat, day/night, and all-weather environment scenes. A data base generation system develops the computer image generated backgrounds. There are also twelve consoles that can be manned by pilots or operators to simulate and study multiple engagements in real-time. Like the cockpits, the consoles can be reprogrammed to meet specific requirements. More than 100 technical staff support the facility operation, including a new tower that was added for real-time sensor testing. The speaker noted that it was the largest facility of its type in the US and reportedly cost more than 100 million dollars to develop to its current capability.

The next paper (Condon) provided an overview of the NASA/AMES results of investigations into the factors influencing the validity of simulated nap of the Earth (NOE) flight. Although a comprehensive program to quantify an understanding of simulator fidelity does not exist, the results of several individual studies conducted at Ames do provide some valuable insights. First, the Ames simulation capabilities were described, followed by a discussion of three investigations specifically concerned with simulation validity: (1) the influence of simulator motion and visual cue variations on helicopter autorotative landing; (2) a comparison of motion and flight results for a UH-60 performing selected NOE maneuvers; and (3) the influence of simulator motion and maneuvering intensity in NOE flight on symptoms of motion sickness. The paper concludes with a discussion of approaches to mitigate the effects of poor simulator fidelity on NOE simulation results.

The following paper (Seavers) details some of the experiences and results gained from two man-in-the-loop experimental trials using the RAE Air Combat Simulator. Various types of air to air missiles and aircraft weapon systems have been employed against a variety of 'threat' aircraft. The RAE single dome Air Combat Simulator (ACS) was used; it consists of a 30 ft diameter dome with a fixed representative fast jet cockpit situated near the dome centre. A sky/ground image with target and missile images is projected onto the interior surface to give the pilot the illusion of participating in air combat. Weapon system integration of radar, missile systems and helmet mounted display systems is one of the most effective ways to improve the air combat performance single seat fighter aircraft. The use of real-time, man-in-the-loop, air-combat simulators is an effective approach to explore future implementations and novel fire control strategies integrated with sensor systems and missile concepts.

The last paper (Killberg) was given by an experienced USAF fighter pilot whose messages were: (1) that the use of simulation in the design and development of the cockpit man-machine interface for advanced, multisensor aircraft is not always successful; (2) the traditional cockpit design philosophy of one panel for each subsystem, and one function per switch, is no longer feasible; and (3) the tremendous increase in the number of sensors and avionics subsystems which must be integrated into the cramped cockpit of a modern fighter make fundamental change in the design an absolute necessity. He illustrated his presentation with two examples: the F-16 multi-stage cockpit improvement program and the F-15E dual role fighter cockpit. In general, the presentation reflected the awareness, not of the shortcomings of pilot-in-the-loop simulations; but rather, the recognition that most problems can be solved if anticipated.

The five papers presented a very interesting collection of specific examples of pilot-in-the-loop simulations. In particular, the last paper presented specific recommendations on the role and usefulness of this type of simulation.

ROUND TABLE DISCUSSION

The chairman of the symposium, Mr. S. Leek (UK), presided over the closing discussion which essentially consisted of comments from panel members Dr. A. Benoit (BE), Pr. R. Onken (GE), Captain A. Sezgin (TU), and Mr. S. Haaland (US). Dr. P. Silson (UK) also participated.

Comments were made that the explosive growth of computer technology may not continue at the same historical rate and that simulation tools are only as good as the people that use them. The

hope was expressed that perhaps a better use of computers in the education of G&C engineers would help in training and ways to teach students about the newest technology developments.

The continuing role of the large, mainframe computer in design and simulation was also challenged by several speakers.

Several speakers remarked that cost is always an issue and computer aided design and simulation will surely expand in its role as defense budgets are under increasing pressures in each NATO country.

Comments were also made on the required application of computers if modern air traffic is to safely expand and that all future simulation facilities should involve pilots in the earliest stages of design.

Finally, the comment was made that not enough papers dealing with methodology and design were presented. Then the closing ceremony was conducted.

REACTION OF THE SYMPOSIUM PARTICIPANTS

About 30 standard questionnaires were received from the participants. Overall, the meeting was rated as very good by 40%, good by 40%, and satisfactory by 20% of the respondents. A 75% majority felt that most of the papers met the published objectives of the meeting and 25% said that 1/2 of the papers met the objectives. A 67% majority said that about 1/2 the papers selected were of personal interest to them; 27% said most were of interest, and only 6% said very few of the papers were of interest. An 80% majority said the general level of the papers was satisfactory; 7% thought them too deep, and 13% too superficial. Fifty percent found most of the speakers effective in presenting their topics while 50% said only half the speakers were effective in presenting the papers. Ninety percent felt there was sufficient time for discussion after each presentation. Eighty percent felt that the language did not cause a problem.

The major criticism, which was shared by the writer and 50% of the participants, was that only 50% of the speakers were effective in presenting their topics. This is an often heard complaint at all engineering symposia; we engineers need to sell our ideas better!

Finally, several commented on the need for a more theoretically oriented symposium including tools for simulation and analysis.

CONCLUSIONS AND RECOMMENDATIONS

The symposium was intended to cover all stages of the development process. Thirty-one papers were presented and they did, in fact, cover all stages of the development process - from computer-aided preliminary design through hardware-in-the-loop simulations.

A major development observed was on the increasing use of workstations and microcomputers to do the jobs that were formerly performed by large mainframe computers. The smaller machines have always been superior to mainframes in terms of user turn-around time, user-friendliness and graphical capability. Now with the use of RISC the smaller machines have central processing unit times which are becoming competitive with those of super-computers. The cost of the small machines is measured in thousands rather than millions of dollars and the small army of technicians, required for the mainframes, have been eliminated. This leads to much more "bang/buck", as was defined by one of the authors at the symposium.

Another trend observed was the increasing use of computer graphics and computer visualization. The interactive nature of the microcomputer and workstation permits a real-time visualization of events which is not possible with a mainframe. Again this is being made possible by special processors and/or workstation/microcomputer capabilities. Image formation, which has been used by Hollywood for nearly a decade, seems to have come of age in this new engineering computer environment. The use of computer graphics and visualization should aid in the understanding of and speed up the guidance and control design process.

One paper reported on the use of TRANSPUTERS in parallel processing architectures. TRANSPUTERS are devices that aim to avoid the problems of conventional serial processors by

providing four links that can be connected to four other TRANSPUTERS. TRANSPUTERS which originally needed a special programming language and a new way of programming, are being used in many applications with alternate software languages, such as ADA, and toolsets now becoming available.

Several papers reported on the uses of high-level symbolic programming languages as opposed to the traditional lower-level FORTRAN approach. In one approach, differential equations are coded as they would appear mathematically and integrations are automatically handled by the higher-level language. It is clear that the trend is to making "user-friendly" simulation and analysis packages available to the engineer at every level of aerospace design.

A minor disappointment, if it could be called that, was a lack of sufficient papers to explain the methodology to be applied in developing various simulations. Methodology applies to theory and application (the how and the why). Too many of the papers presented the results rather than the reasoning that led to the approach taken. It is not useful to hear about specific proprietary software or simulation packages (generic to a company or facility) that cannot be used anywhere else; at least, lessons learned should be presented, as well as, alternate approaches.

The major disappointment was the lack of papers dealing with the methodology and new techniques relating to overall approaches for computer-aided system design, possibly in a paperless environment. For several decades now, the engineering design and evaluation process has benefitted from the availability of general purpose analog and digital computers. What is now emerging is intelligent, paperless design environments. These design environments can be viewed as a logical extension of recent developments in CAD/CAM/CAE tools and software development environment. Rapid progress in parallel and distributed computation, man-machine interfaces, and computer science now affords an opportunity to create integrated design environments that will make it possible to: (1) explore more of the design solution space, earlier in the design process, (2) make the performance/reliability impacts of design tradeoffs more visible during the design process, (3) enforce design discipline and adherence to standards throughout the design process, (4) prevent/detect design errors, (5) resolve design conflicts, (6) facilitate more timely communication and coordination among designers and managers, and (7) capture and document the design process. While some of these topics were covered in a fragmented way, no unified picture of computer-aided system design in a paperless environment emerged.

What form will these new system design environments take? Since they are only beginning to emerge, it is difficult to foresee the many forms that these environments might take. However, it seems likely that they will embody a network of distributed, interactive, user-friendly interfaces (exploiting keyboards, voice, high-definition graphics, etc.) that serve the needs of a multi-disciplinary design team and its managers throughout the design process (from conceptual design through detailed design and evaluation). These interfaces will give individual designers and managers rapid access to the myriad of tools (design tools, evaluation tools, simulation tools, software development tools, documentation tools, management tools, etc.) that are required to support the design of complex, modern engineering systems.

Taking advantage of these environments, algorithm designers should be able to rapidly iterate their designs, quantitatively evaluating the performance of the algorithms themselves and assessing the impacts of that performance on more global metrics of system effectiveness. Once satisfactory performance is attained, the production of "flight code" and documentation would be largely automated. Similar services would be available to hardware designers, enabling them to gain a greater appreciation for the impacts of alternative design decisions on a broad spectrum of metrics including weight, volume, manufacturability, operability, reliability, maintainability and cost. Systems engineers should be able to gain visibility into the global impacts of subsystem design decisions and to resolve conflicts among and rationalize requirements across subsystems, thereby achieving more balanced (and less conservative) designs than are typically achieved today. Managers should be able to track the design process more effectively, and quickly generate reliable summary information that is needed to support management and customer reviews. Finally, the automated archiving of design information in an intelligent database should make the production of comprehensive, accurate, timely documentation easier and less costly.

As a concluding comment, the Guidance and Control Panel should consider a symposium, or working group, that would deal exclusively with computer-aided system design issues in a paperless environment.

APPENDIX
FINAL PROGRAM
GUIDANCE AND CONTROL PANEL 50TH SYMPOSIUM
COMPUTER AIDED SYSTEM DESIGN AND SIMULATION

Opening ceremony by Col. Doğan Kaya, Chief, Dept. of Research and Development, Ministry of National Defense, TU

Keynote Address by Mr. David Humphries, Assistant Chief Scientific Advisor (Projects & Research) MOD, Whitehall, London, UK

SESSION I - COMPUTER AIDED SYSTEM DESIGN
Chairman: Dr. A Benoit (BE)

11: Méthodologie de développement d'algorithmes de commande pour l'optimisation des performances rotor par commande multicyclique sur hélicoptère (OCAPI)
Algorithms development methodology for performance-optimized multicyclic rotor commands.
S Germanetti — Division Hélicoptères, Aérospatiale Marignane, FR.
B. Gimonet — ONERA/CERT/DERA, Toulouse, FR.

12: A decentralized controller for highly augmented aircraft
K.A. Ünyelioğlu, — Electronical and Electronics Engineering,
A.B. Özgüler — Bilkent University, Maltepe, Ankara, TU.

13: Parameter space design of robust flight control systems
A. Cavallo, G. De Maria, — Dipartimento di Informatica & Sistemistrica, Universitá degli Studi di Napoli, IT.
L. Verde — CIRA SpA, Capua (CE), IT.

14: Computer aided design and simulation of the automatic approach and landing phase of a combat aircraft
F. D. Langer — MBB Aircraft Division, 8000 München 80, Ottobrunn, GE.

SESSION II - SIMULATION TECHNOLOGY FOR MISSILE APPLICATIONS
Chairman: Dr. E. Zimet (US)

21: Conception d'autodirecteurs rigides
Conceptual design of strapdown seekers
F. Bertrand, M. Breuzet — THOMSON-CSF, Division Electronique de Missiles, Malakoff, FR.

22: Simulations numériques pour le développement de systèmes de navigation de missiles
Computer simulation for the development of missile navigation systems
D. Berton, D. Duhamel, — SAGEM, Missile & Space Guidance Systems Unit,
G. Cuvelier — Eragny R&D Center, Cergy-Pontoise, FR.

23: Withdrawn.

24: Withdrawn.

25: Guided weapon simulation
J.L. Quesada — INTA, Madrid, SP.
R. Minguez, P. Segurola — SENER, Madrid, SP.

26: GWSIM - A computer based design and simulation package for land based and air weapon systems
P.M.G. Silson, B.A. White — Royal Military College of Science, Cranfield, Wilts, UK.

27: The microcomputer as a tool for guidance and control visualization
P. Zarchan — C.S. Draper Laboratory, Inc., Cambridge, MA, US.

SESSION III - SIMULATION TECHNOLOGY FOR AIRCRAFT APPLICATIONS
Chairman: Captain A Sezgin (TU)

31: A unified approach to simulat'.n software and operational software
A. Mattissek — LITEF GmbH, Freiburg, GE.

32: A simulation study for analysing pilot's rule-based behavior
B. Döring — Forschungsinstitut für Anthropotechnik, Wachtberg-Werthhoven, GE.

33: Symbolic generation of aircraft simulation programmes
P. Maes, P.Y. Willems — Université Catholique de Louvain, Louvain- la-Neuve, BE.

34: Outils Formels et outils de simulation: un atelier cohérent
Formal tools and simulation tools: a coherent workshop
P. Sch'rle — AMD-BA, Saint Cloud, FR.

35: A'rcraft control system design, synthesis, analysis and simulation tools at Aermacchi
L. Mangiacasale, L.V. Cioffi, C.A. Bonatti — Air Vehicle Technology, Aermacchi SpA, Varese, IT.

36: Cockpit mock up CMU, a design and development tool
C. Weber — Elektronik-System-GmbH, München, GE.

37: Management of computer-aided cor trol system design - from concept to flight test
B.N. Tomlinson, G.D. Padfield, P.R. Smith — Royal Aerospace Establishment, Bedford, UK.

SESSION IV - HARDWARE-IN-THE-LOOP SIMULATION
Chairman: Mr. S. Haaland (US)

41: Real-time hardware-in-the-loop simulation for "ATTAS" and "ATTHES" advanced technology flight test vehicles
P. Saager — DLR, Institut für Flugmechanik, Braunschweig, GE.

42: Hardware-in-the-loop simulation at the Naval Weapons Center
R.A. Licklider, A.B. Galloway, F. Schiavone, E.J. Bevan, W. Williams — Naval Weapons Center, China Lake, CA, US.

43: Simulation of multi-path for semiactive missiles
R.M. Smith, J.Y. Yee, C.S. An, A.L. Haun — Naval Weapons Center, China Lake, CA, US.

44: A new approach to hardware-in-the-loop missile simulation
C-H. Oertel, K. Alvermann, R. Gandert, B. Gelhaar — DLR, Institut für Flugmechanik, Braunschweig, GE.

45: Computer graphics in hardware-in-the-loop missile simulation
B.J. Holden — Naval Weapons Center, China Lake, CA, US.

SESSION V - SYSTEMS APPLICATIONS
Chairman: Dr. M.J. Pelegrin (FR)

51: Modelling of land based air defense systems in research and procurement support
K.A. Hurst, S. Flynn — Defensive Systems Department, Royal Aerospace Establishment, Farnborough, Hampshire, UK.

52: Integration of a realistic airline/aircrew/aircraft component in ATC simulation
A. Benoit, S. Swierstra — European Organisation for the Safety of Air Navigation, Brussels, BE.

53: NAVPAK - Simulation tools for design of high performance integrated navigation systems
J.Z. Zywiel, J.G.A. Hepburn, B.M. Scherzinger — Advanced Technology Center, Honeywell Ltd, Markham, Ontario, CA.

54: Application of modelling and signal processing in air defence
N.M. Vepa, W. Kreuzer — Contraves GmbH, Stockach, GE.

55: The use of system simulation during the definition phase of the passenger transport aircraft MPC75
D. Dey, A. Kröger — Deutsche Airbus GmbH, Hamburg, GE.

SESSION VI - PILOT-IN-THE-LOOP SIMULATION
Chairman: Pr. Dr. Ing. R.C. Onken (GE)

61: COMTESS - Combat mission training evaluation and simulation system
W. Kraft, U. Krogmann, H.P. Müller, E. Platt — Bodenseewerk Gerätetechnik GmbH-BGT, Überlingen, GE.

62: Integrated technology development laboratories
D.E. Dewey — Boeing Advanced Systems, Seattle, WA, US.

63: Simulation of nap-of-earth flight in helicopters
G.W. Condon — Flight Systems and Simulation Research Division, NASA Ames Research Center, Moffett Field, CA, US.

64: Results of man in the loop simulator experiments using air-to-air missile models
N. Seavers — Royal Aerospace Establishment, Farnborough, Hants, UK.

65: The development of avionics - intensive, multi sensor cockpits: simulation doesn't always equal success
C.G. Killberg — 6515th Test Squadron/CD, Edwards Air Force Base, CA, US.

ROUND TABLE DISCUSSION

CLOSING CEREMONY

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AR-283	ISBN 92-835-0595-6	UNCLASSIFIED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title TECHNICAL EVALUATION REPORT ON THE 50th GCP SYMPOSIUM ON COMPUTER AIDED SYSTEM DESIGN AND SIMULATION

7. Presented at

8. Author(s)/Editor(s)	9. Date
Dr George T.Schmidt	November 1990

10. Author's/Editor's Address	11. Pages
The Charles Stark Draper Laboratory Inc., (MS 2A) 555 Technology Square, Cambridge Massachusetts 02139, United States	20

12. Distribution Statement This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors

Avionics	Microcomputers
Computers	Navigation
Control	Pilot-in-the-loop
Guidance	Simulation tools
Hardware-in-the-loop	Systems design

14. Abstract

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AGARD Advisory Report No.283
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ISBN 92-835-0595-6

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ISBN 92-835-0595-6

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Pintor Rosales 34
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ETATS-UNIS
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PAYS-BAS
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Scientifique and Technical Aerospace Reports (STAR)
publié par la NASA Scientific and Technical
Information Branch
NASA Headquarters (NIT-40)
Washington D.C. 20546
Etats-Unis

Government Reports Announcements (GRA)
publié par National Technical Information Services,
Springfield
Virginia 22161
Etats-Unis

Imprimé par Specialised Printing Services Limited
40 Chigwell Lane, Loughton, Essex IG10 3TZ